Coherent-Phase Cavitation-Monitoring System for Turbomachinery

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Cavitation is the process of boiling fluid that occurs when local fluid dynamic pressures in the areas of accelerated flow drop below the vapor pressure of the fluid. When cavitation occurs within the turbopumps of liquid rocket engine propulsion systems, it can severely degrade overall system performance, cause excessive structural vibration, and damage turbopump blades. The Coherent-Phase Cavitation-Monitoring System will utilize an innovative coherent-phase wide-band demodulation technique to accurately detect the cavitation inception point occurrence, its severity, and the type of cavitation, with an on-line, continuous monitoring system. The method's effectiveness is attributed to its unique ability to accurately extract cavitation-generated signatures without being subject to commonly encountered high-frequency discrete interference.

Traditionally, the performance of turbomachinery and other fluid dynamic systems has been very difficult to determine. Therefore, a reliable method for determining cavitation losses in turbomachinery systems is crucial in assessing overall system performance. The principle for cavitation detection is based on a unique phenomenon associated with cavitation physics, i.e., when cavitation occurs in a rotating system, the periodic rotational components (such as revolutions per minute and their harmonics) will amplitude modulate the wide-band, high-frequency noise generated from the collapse of cavitation bubbles. Such a wide-band modulation phenomenon (a narrow-band discrete signal multiplied by wide-band random noise) will generate hidden periodicity in a monitored dynamic response signal, thus providing a unique signature in the high-frequency region conducive to cavitation detection. However, because of lacking nonlinear-phase information, conventional linear spectral analysis is unable to identify such hidden periodicity within a cavitation-generated wide-band modulation signal.

Prior techniques for cavitation detection have utilized full-wave rectification spectral analysis to perform wide-band demodulation on monitored dynamic measurement signals. The full-wave rectification wide-band demodulation method detects a cavitation signature by demodulating the dynamic signal over an isolated band of high-frequency noise floor using the principle of envelope detection. The onset and existence of cavitation are determined by the recovery of the hidden periodicity within the cavitation-generated wide-band modulation signature. The magnitude of the modulation is used to determine the cavitation severity as a function of system operational parameters (rotational speed, impeller geometry, developed heat, etc.).

In actual applications, the conventional cavitation detection technique suffers from a severe limitation. Since the hidden periodicity is recovered from the envelope signal of a wide-band high-frequency noise floor, any discrete components present in this high-frequency region of the raw signal will erroneously generate discrete peaks in the resulting demodulated signal, appearing to be recovered hidden periodicity. This limitation is critical in assessing the performance of rocket engines under severe operational environments in which other vibration sources contribute many high-frequency components that can corrupt the demodulation signal.

The new coherent-phase wide-band demodulation technique provides an effective method to avoid such discrete interference. The method is based on the fact that for an ordinary (linear) wide-band noise signal, the spectral components at different frequencies are statistically independent of each other. However, for a wide-band modulation noise signal with hidden periodicity (nonlinear), a unique coherent-phase relationship exists among all interacting components.

The new technique can thus identify hidden periodicity by searching for such a coherent-phase relationship. An inherent characteristic (also a highly desirable one) of the method is that it would not be affected by any linearly superimposed discrete component since only the phase information is utilized for cavitation signature detection. As a result, the coherent-phase information provides an effective way to overcome the critical limitation of discrete interference suffered by the conventional method. The new technique utilizes a phase-only filtering technique along with an envelope detector to search for the unique cavitation-generated coherent-phase relationship.

Application examples to the alternate turbopump development high-pressure fuel turbopump test data have been utilized to demonstrate the performance of the new techniques. Figures 87(a) and 87(b) show the raw power spectral densities of two different pressure measurements during test TTB–038. 6N sideband anomalies are present in the first measurements, but are not observable at all in the raw spectral densities of the second measurement.

In order to determine whether these anomalies were related to cavitation-induced vibration, wide-band demodulation has been performed to identify whether a cavitation-generated hidden periodicity was presented in the wide-band noise floor of the two measurements (figs. 87(c) and 87(d)). No hidden periodic components were recovered in the first measurement (fig. 87(c)); however, the wide-band demodulation spectral density of the second measurement recovered strong hidden periodicity at 6N±a from the wide-band noise floor. The periodic modulating components of the wide-band modulation signal were composed of not only the 6N component, but also its sideband components (the 6N±a anomalies). Such nonsynchronous-related modulating components associated with the cavitation phenomenon were also observed in other pump tests and in inducer MSFC water-flow tests, indicating that the 6N±a sideband anomalies should be a cavitation-related phenomenon.

In summary, cavitation within the turbopumps of liquid rocket engine propulsion systems can: (1) severely degrade overall system performance, (2) cause excessive structural vibration, and (3) create erosion damage to turbopump blades. Therefore, an effective on-line cavitation detection and monitoring system must provide critical performance information during the engineering development of efficient fluid dynamic elements. Moreover, the system must provide this same capability in monitoring operation fluid dynamic systems in the field. Ultimate benefits include efficient turbine designs, lower maintenance costs of on-line systems, and reduced risks of catastrophic failure of on-line fluid dynamic systems.

An effective cavitation detection and monitoring method has strong commercial applications for various turbomachinery systems. In particular, the hydropower industry (almost all hydroturbines experience cavitation and undergo excessive erosion and performance degradation), the nuclear power industry (boiler feedwater pumps), and the U.S. shipbuilding industry (commercial and military surface ship propellers) could all benefit from on-line cavitation monitoring systems.

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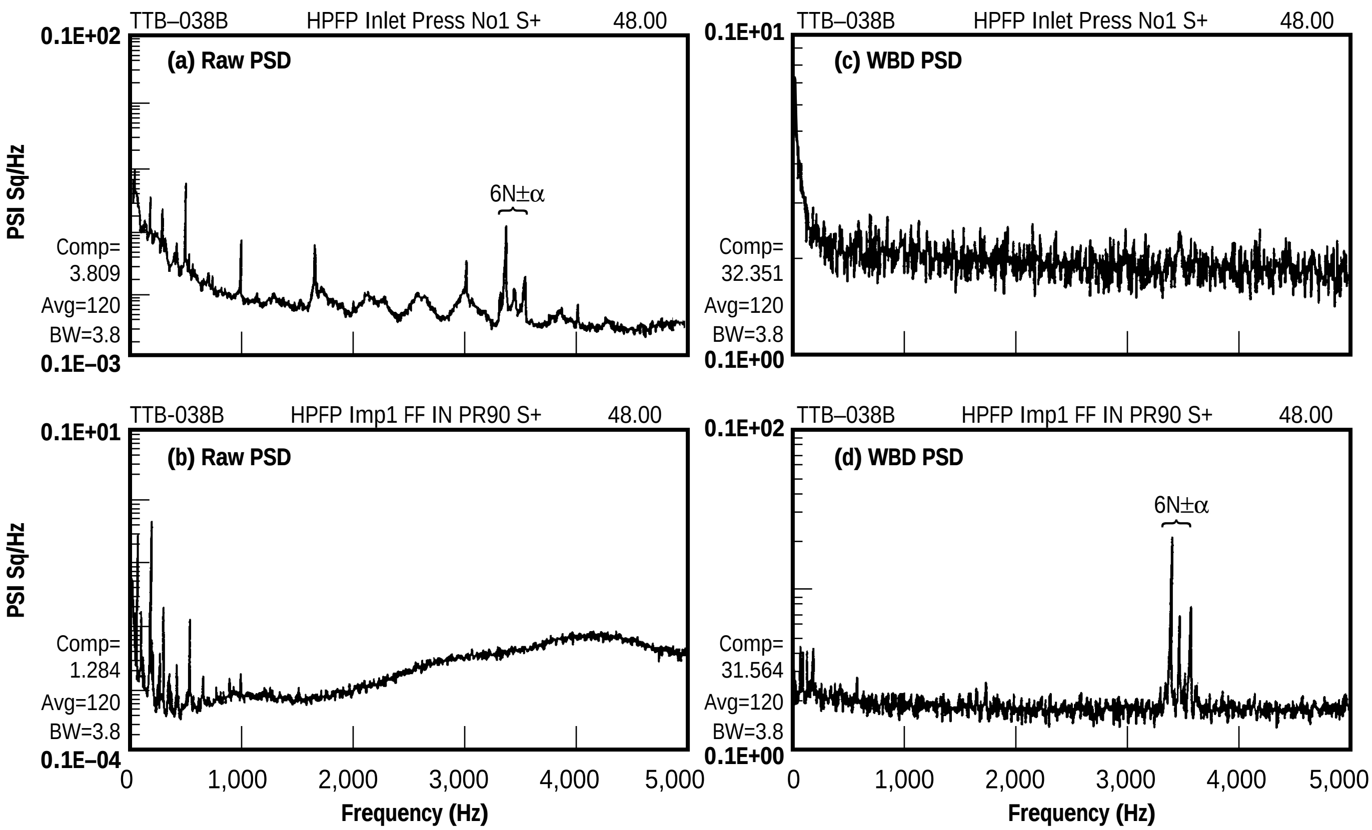

FIGURE 87.—Power spectral densities of alternate turbopump development high-pressure fuel turbopumps: (a) raw power spectral density—inlet pressure number 1; (b) raw spectral density—first-stage impeller pressure; (c) wide-band demodulation spectral density—inlet pressure number 1; (d) wide-band demodulation—first-stage impeller pressure.